Analysis of pC-interactions at Momentum of 4.2 GeV/c Within Framework of FRITIOF and Cascade Models

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Abstract

Experimental data on multiplicities and kinematical characteristics of π^-, π^+ mesons and protons in the interactions of protons with carbon nucleus at momentum 4.2 GeV/c in a dependence of collision centrality are analyzed. Parameter Q which is a difference between multiplicities of positive and negative charged particles without multiplicity of slow protons with momentum less than 0.3 GeV/c in an event, is taken as a criteria of collision centrality. The experimental data on events with different centrality are compared with predictions of the cascade-evaporation model and the modified FRITIOF model.

It is shown that the cascade model does not reproduce decrease of the average transverse momenta of participating protons with increase of the centrality. The model overestimates the yield of the particles in the target fragmentation region.

For the first time, non-nucleonic degrees of freedom in nuclei (Δ^+, Δ^0 isobars) are taken into account in the FRITIOF model, and a commonly good description of the secondary particles characteristics is reached.

A large volume of experimental data on hA- and AA-interactions at the momentum of 4.2 GeV/c has been obtained with the help of 2-meter propane bubble chamber of the laboratory of High Energy of JINR. The different theoretical models: Cascade Evaporation Model (CEM)[1, 2], Quark-Gluon String Model (QGSM)[3], and FRITIOF model [4] were used for the experimental data analysis. It was shown that the CEM describes quite well the main characteristics of proton-carbon (pC) interactions. For carbon-carbon (CC) interactions, the CEM overestimates the produced particle multiplicity. The situation becomes worse at a description of the characteristics of interactions with heavy nuclei, for example, A+Ta collisions. The study of the interactions with heavy nuclei is interesting for various applied tasks such us solving of the problems connected with the creation of the subcritical nuclear reactors driven by accelerator. Statistics of the interactions with heavy nuclei is small as a rule, and methodical corrections due to absorption of produced particles in target are large. But one can study the multi-nucleon interactions dominated in the interactions with the heavy nuclei using the data about interactions with light nuclei, in particular pC-interaction at different centrality of proton collision with carbon nuclei presented in Ref. [5].

At the experimental study π^+, π^--mesons, participating protons at the momentum $p > 0.3$ GeV/c and evaporated protons at the momentum $0.15 \leq p \leq 0.3$ GeV/c were considered. Two groups of the protons were distinguished: protons at the momentum from 0.3 to 0.75 GeV/c (these are basically proton-participants from target nuclei), and the protons at the momentum more than 0.75 GeV/c. The last group consists of projectile protons interacted with the target nucleus and part of the protons of the carbon nuclei obtained large transverse momentum at the interaction. The average characteristics of the produced particles are given in the tables 1, 2.

The parameter Q was accepted as a measure of collision centrality of the pC-interactions. It was defined as: $Q = n_+ - n_- - n_{p.ev}$, where n_+ and n_- were the multiplicities of positive and negative charged particles, correspondingly, and $n_{p.ev}$ was the multiplicity of the evaporated protons. The value of Q is equal to total charge of the particles taking an active part in the interaction. It correlates with impact parameter magnitude. The value of centrality Q increases with decrease of the impact parameter.

The table 1 gives the number of the analyzed pC-events and the average multiplicities of secondary particles for all pC-interactions and for six group of events at Q=1, 2, 3, 4, 5, ≥ 6. One can see, the peripheral interactions (Q$\leq$ 2) presents more than 70 % of all inelastic pC-collisions. The part of most central interactions (Q more than 4) is small and is about few percents. As consequence, the all pC-interactions are characterized by the average number of the participating protons $< n_p^{part} >$ less than 2. The average multiplicity of π^+- mesons exceeds considerably the average multiplicity of π^--mesons. That is typical for proton interactions with symmetrical nuclei with $N_p = N_n$.

We use the CEM [6] and two versions of modified FRITIOF model [7, 8] for analysis of the experimental data. In the modified model FRITIOF, it is assumed [9] inelastic interaction of projectile nucleon and target nucleon initiates reggeon exchanges between spectator nucleons of the nucleus. In the cascade model, these exchanges are interpreted as NN-collisions. We have used two variants of the FRITIOF model. In the first version (DFRITIOF), it was considered the part of the nucleons knocked out by the reggeon cascade are emitted as Δ^0- and Δ^+-isobars. In the other variant of the model, the Δ-isobars in the spectator part of nucleus were not taken into account.

Table 1: The average multiplicities of the particles in the pC-interactions at the momentum of 4.2 GeV/c at the different collision centralities, e - experiment [5], m - the FRITIOF model calculations with Δ-isobars.

Q		1	2	3	4	5	6	all events
N_{ev} (%)	e	2289 (27.3)	3814 (45.6)	1477 (17.6)	575 (6.9)	164 (1.9)	52 (0.62)	8371 (100)
	m	28457 (28.4)	37635 (37.6)	16675 (16.7)	9551 (9.6)	5166 (5.2)	2516 (2.5)	100000 (100)
$< n_{\pm} >$	e	2.72 $\pm$0.08	3.15 $\pm$0.02	4.697$\pm$0.04	5.73 $\pm$0.07	6.72 $\pm$0.12	7.60 $\pm$0.20	3.61 $\pm$0.02
	m	2.152$\pm$0.008	2.926$\pm$0.007	4.594$\pm$0.014	6.00 $\pm$0.02	6.96 $\pm$0.02	7.71 $\pm$0.03	3.627$\pm$0.007
$< n_{\pi^-} >$	e	0.522$\pm$0.013	0.321$\pm$0.007	0.423$\pm$0.016	0.476$\pm$0.027	0.43 $\pm$0.05	0.36 $\pm$0.07	0.407$\pm$0.006
	m	0.479$\pm$0.004	0.321$\pm$0.003	0.424$\pm$0.005	0.448$\pm$0.006	0.45 $\pm$0.01	0.46 $\pm$0.01	0.406$\pm$0.002
$< n_{\pi^+} >$	e	0.416$\pm$0.010	0.660$\pm$0.008	0.965$\pm$0.020	1.22 $\pm$0.04	1.40 $\pm$0.08	1.58 $\pm$0.16	0.706$\pm$0.007
	m	0.379$\pm$0.003	0.662$\pm$0.004	0.787$\pm$0.006	0.857$\pm$0.008	0.89 $\pm$0.01	0.93 $\pm$0.02	0.640$\pm$0.002
$< n_p^{part} >$	e	1.054$\pm$0.015	1.743$\pm$0.010	2.526$\pm$0.024	3.22 $\pm$0.04	4.02 $\pm$0.09	5.10 $\pm$0.18	1.860$\pm$0.010
	m	1.088$\pm$0.005	1.658$\pm$0.004	2.624$\pm$0.007	3.54 $\pm$0.01	4.46 $\pm$0.02	5.75 $\pm$0.03	2.085$\pm$0.004
$< n_p^{part} >$	e	0.241$\pm$0.009	0.584$\pm$0.009	1.212$\pm$0.024	1.84 $\pm$0.05	2.61 $\pm$0.10	3.39 $\pm$0.21	0.747$\pm$0.009
$0.3 < P \leq 0.75$ (GeV/c)	m	0.114$\pm$0.002	0.454$\pm$0.003	1.219$\pm$0.006	2.03 $\pm$0.01	2.89 $\pm$0.02	4.17 $\pm$0.03	0.855$\pm$0.004
$< n_p^{part} >$	e	0.588$\pm$0.020	0.740$\pm$0.018	0.664$\pm$0.027	0.57 $\pm$0.04	0.47 $\pm$0.06	0.56 $\pm$0.11	0.668$\pm$0.01
$P > 1,4$ (GeV/c)	m	0.785$\pm$0.006	0.794$\pm$0.005	0.712$\pm$0.007	0.62 $\pm$0.01	0.54 $\pm$0.01	0.44 $\pm$0.01	0.739$\pm$0.003
$< n_p^{ev} >$	e	0.732$\pm$0.020	0.425$\pm$0.013	0.779$\pm$0.026	0.82 $\pm$0.04	0.87 $\pm$0.03	0.56 $\pm$0.08	0.640$\pm$0.009
$0.15 < P \leq 0.3$ (GeV/c)	m	0.206$\pm$0.004	0.284$\pm$0.004	0.759$\pm$0.009	1.15 $\pm$0.01	1.16 $\pm$0.01	0.57 $\pm$0.01	0.476$\pm$0.003
$< n_p^{ev} >$	e	5.32$\pm$0.02	0.49$\pm$0.01	3.15$\pm$0.03	2.22 $\pm$0.05	1.15 $\pm$0.01	0.11 $\pm$0.15	4.20$\pm$0.02
$P < 0.15$ (GeV/c)	m	5.80 0.$\pm$0.003	4.716$\pm$0.003	3.255$\pm$0.009	1.89 $\pm$0.01	0.94 $\pm$0.01	0.21 $\pm$0.01	4.204$\pm$0.006

Table 2: The average momenta and angles of π-mesons in the pC-interactions at 4.2 GeV/c at the different Q, e - experiment [5], m - the FRITIOF model calculations with Δ- izobars.

Q		1	2	3	4	5	≥6	all events
$< p_{\pi-} >$,GeV/c	e	0.567±0.014	0.518±0.010	0.424±0.014	0.375 ±0.018	0.38±0.04	0.45±0.07	0.503±0.007
	m	0.496±0.003	0.449±0.003	0.378±0.003	0.333± 0.003	0.314±0.004	0.295±0.005	0.429±0.002
$< p_t^{\pi-} >$,GeV/c	e	246±0.005	0.255±0.004	0.248±0.007	0.236±0.011	0.215±0.025	0.27±0.06	0.248±0.003
	m	0.241±0.001	0.222±0.001	0.214±0.001	0.207± 0.002	0.208±0.002	0.199±0.003	0.224±0.001
$< \theta_{\pi-} >$,grad	e	45.2±1.0	49.5±1.0	57.3±1.5	62.1±2.3	62.3±4.9	62.3±11.0	50.8±0.6
	m	47.4±0.3	49.6±0.3	56.4± 0.4	60.9±0.6	63.1±0.8	66.8±1.1	52.4±0.2
$< p_{\pi+} >$,GeV/c	e	0.564±0.007	0.554±0.004	0.505±0.006	0.475±0.007	0.430±0.012	0.446±0.020	0.528±0.003
	m	0.592±0.004	0.533±0.002	0.428±0.003	0.373±0.003	0.337±0.002	0.311±0.004	0.480±0.001
$< p_t^{\pi+} >$,GeV/c	e	0.239±0.002	0.269±0.002	0.275±0.003	0.265±0.004	0.267±0.007	0.30±0.012	0.265±0.001
	m	0.238±0.001	0.242±0.001	0.229±0.001	0.217±0.001	0.209±0.002	0.203±0.002	0.232±0.001
$< \theta_{\pi+} >$,grad	e	39.1±0.4	47.7±0.3	55.3±0.5	57.4±0.7	64.9±1.2	68.7±2.0	50.3±0.2
	m	38.2±0.3	44.0±0.2	51.4±0.3	55.2±0.4	58.6±0.5	61.5±0.7	47.6±0.1

Fig. 1 gives presentation of multiplicity distributions of the different types of the produced particles. The largest number of charged particles, registered in pC-interactions, achieves 13, of π^+- and π^--mesons – 4, and of the proton-participants – 8 (with taking into account exchanges $p \to n$ and $n \to p$). The points are the experimental data [5], the solid lines are the calculations by DFRITIOF, dotted lines are the calculations by CEM. As seen, the models describe the distributions quite well. The FRITIOF models with

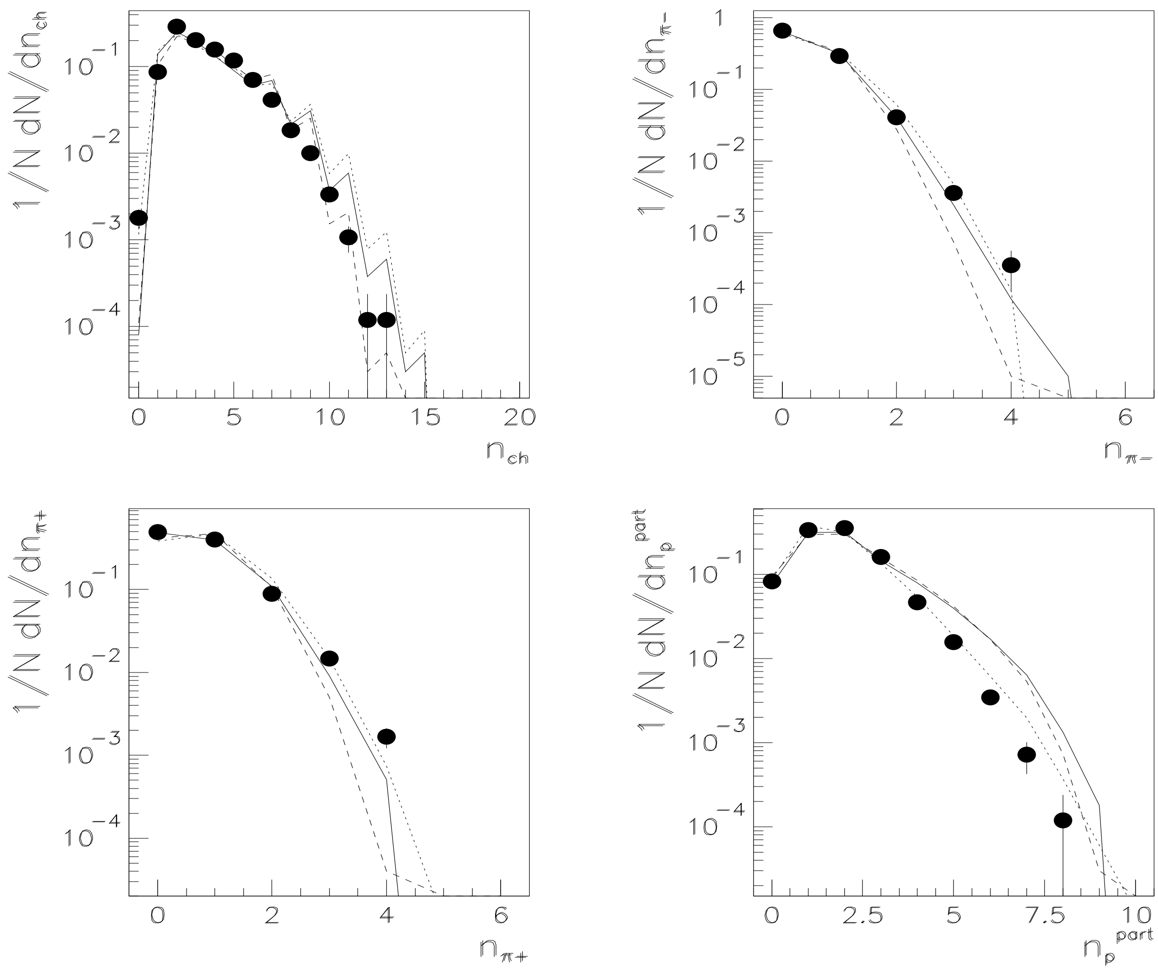

Figure 1: Multiplicity distributions in pC-interactions. Points are the experimental data [5], lines are our calculations.

and without Δ-isobars (solid and dashed lines, respectively) overestimates the proton participant multiplicity production.

Let us consider the average multiplicity dependence on the centrality of the pC-interactions, presented in the table 1 and Fig. 2. One can see, the average multiplicities of all charged particles, π^+-mesons, proton-participants increase considerably passing from peripheral interactions to the central ones. The average multiplicity of π^--meson changes slowly with increase of the parameter Q. The highest value of π^--meson multiplicity is in the events at Q=1 presented mainly pn-interactions. It is interesting, CEM that describes well the multiplicity of π^--mesons in all interactions does not describe the dependence of this multiplicity on Q. At the same time, CEM describes satisfactory the π^+-meson and proton-participant multiplicities increase with enhance of Q. The modified model

FRITIOF also reproduces π^-, π^+ meson multiplicities in all interactions. But the dependencies of π^-, π^+ meson multiplicities on value of Q are not described by model FRITIOF without Δ-isobars. The modified FRITIOF model with Δ-baryons describes quantitative the π^--meson multiplicity at different Q (Fig. 2).

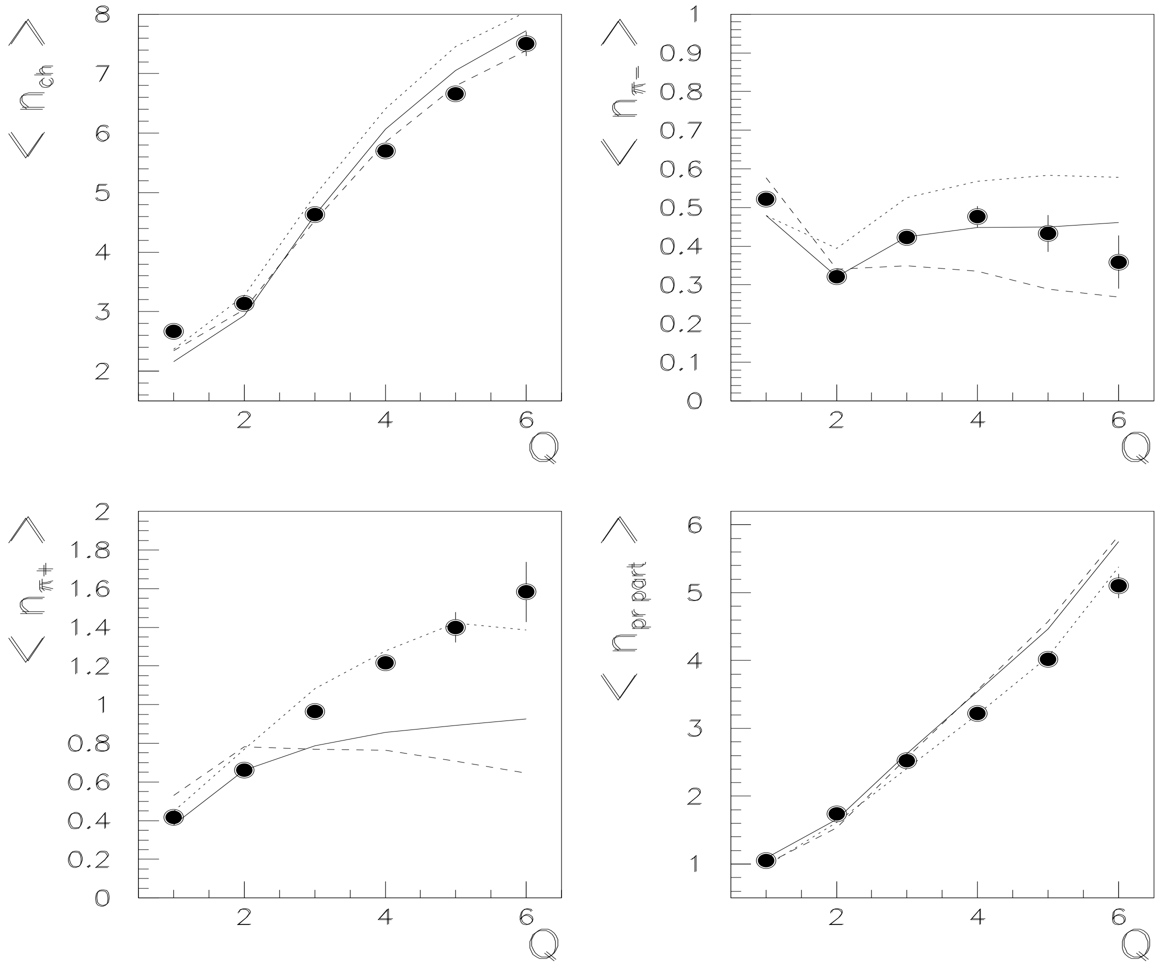

Figure 2: The average multiplicy dependences on Q.

In Fig. 3 the average momenta, transverse momenta, and rapidities of π^-, π^+ mesons are presented. The points are the experimental data of the table 2, solid and dashed lines are the FRITIOF model calculations with and without Δ-isobars, dotted lines are CEM calculations, correspondingly. As seen, the average momenta of pions decrease with increase of the collision centrality. The theoretical models reproduce qualitatively the dependence of the average momenta on the parameter Q. Perhaps, the predictions of the model FRITIOF without Δ-isobars are nearest to the experimental values of the momenta and the transverse momenta of pions. CEM and FRITIOF model with Δ-isobar underestimate the average momenta, the transverse momenta for all groups of the pC-events subdivided by the value of the parameter Q. That is, they assume the preferential production of pions with small momenta. The average values of the polar angles of pions emission enhance with increase of Q. It characterizes the process of pion production. The probability of pion re-scatterings increases with decrease of the impact parameter, that leads to the decrease of the average momenta and the increase of the average emission angles of pion. This causes the weak dependence of the average transverse momenta on the

collision centrality. The calculations by CEM and FRITIOF with Δ-isobars qualitatively reproduce the values of the average rapidities of pions at different Q

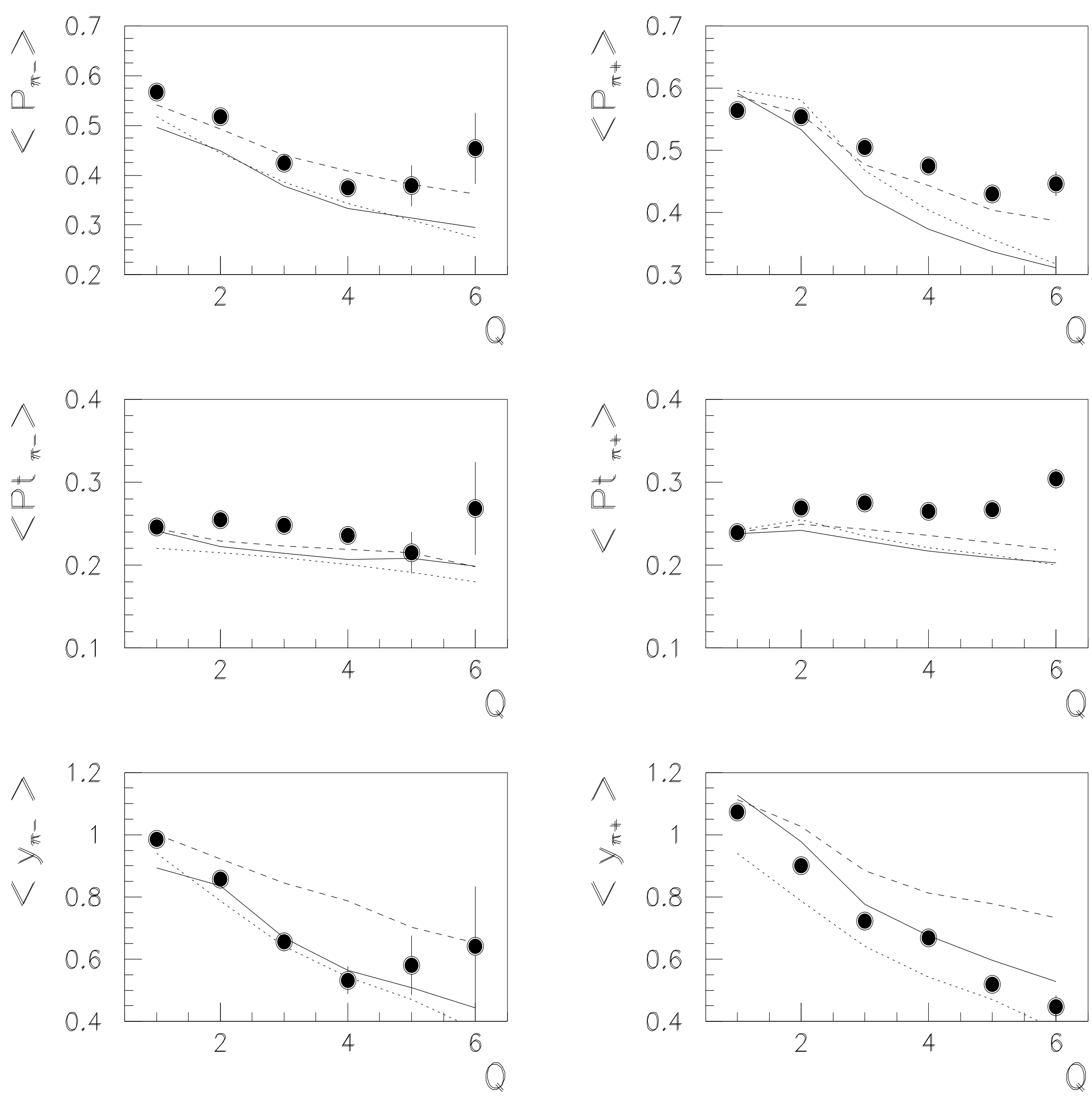

Figure 3: Dependencies of the average momenta, transverse momenta, and rapidities of the produced particles on Q.

The differential distributions on momentum and on rapidity allow one to obtain more specific conclusion about demerits of the applied models. In Fig. 4, the momentum distributions of π^--mesons are presented in the six groups of the pC-events. The predictions and the experimental data are distinguished at very small and large momenta. Taking into account the large experimental errors in the region of large momenta, one can consider the theoretical description as a satisfactory one. Therefore the divergence of the average experimental and theoretical values of momenta is connected with the small momentum region, mainly. According to the Fig 4 (and also next Fig. 5) the CEM overestimates the yield of the soft pions ($p < 300$ MeV/c). The FRITIOF model without Δ-isobars underestimates considerable the production of the soft pions. It explains the large values

of the average momenta calculated by this model. The small value of the average momenta of π^--mesons in the FRITIOF model with Δ-isobars are caused by the insufficient formation of hard pions. On the whole, the momentum distributions of π^--mesons in the separate groups of the pC-events are described satisfactory by the models.

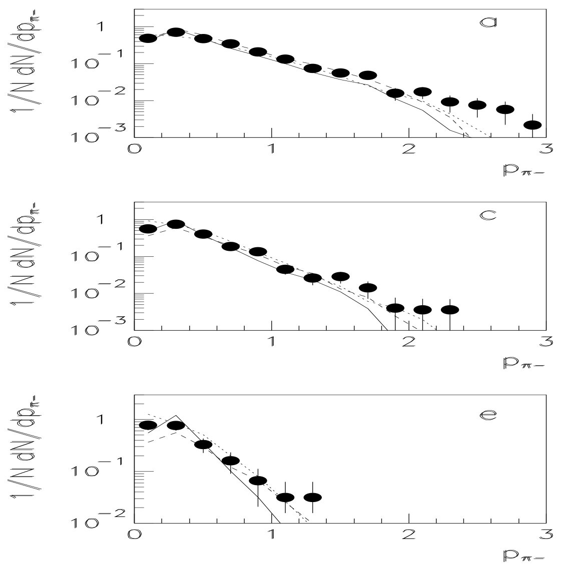

Figure 4: π^--meson momentum distributions at Q = 1, 2, 3, 4, 5 (figs. a – e), and at $Q \geq 6$ (fig. f).

The situation gets complicated at analysis of the momentum distributions of π^+-mesons in the groups of the pC-collisions (Fig. 5). In the groups at Q=1, 2 presented mainly pn- and pp-interactions, a good description of π^+-meson spectra is seen. The models reproduce badly the experimental data in multi-nucleon collisions at $Q \geq 3$. The study of such interactions can lead to a future development of the FRITIOF model.

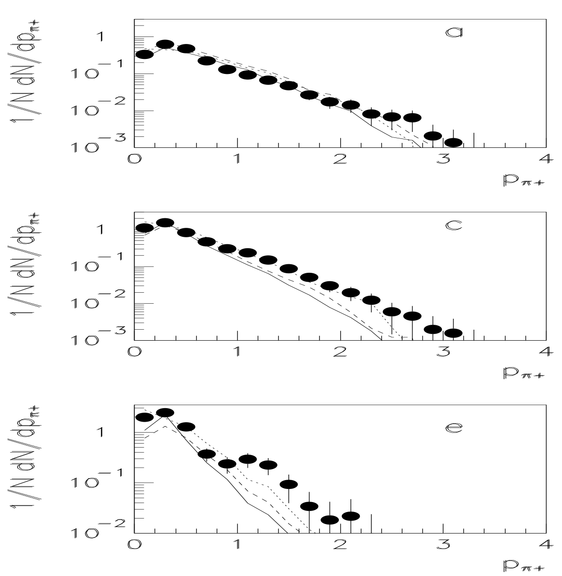

Figure 5: π^+-meson momentum distributions. Notation is the same as on the Fig. 4.

The rapidity distributions of $\pi^{\pm}$-mesons in the studied groups of the pC-events give an

interesting information about correlations between theory and the experiment (Figs. 6, 7). As seen in the Fig. 6 (and also next Fig. 7), the maximum of the y-distribution of pions moves to the region of the carbon nucleus fragmentation with increase of Q. The y-distribution of π^--mesons in the events at Q=1 has two maxima at $y \sim 0.5$ and $y \sim 1.5$. The two peaks structure are absent in the next group. According to the Fig. 6a, the CEM underestimates considerably the multiplicities of the fast π^--mesons. The modified FRITIOF model without Δ-isobars overestimates the multiplicities of π^--mesons in the central region at $y \sim 1.1$. Moreover, it underestimates the multiplicities of produced π^--mesons in multi-nucleon collisions (Fig. 6 c, d, e, f).

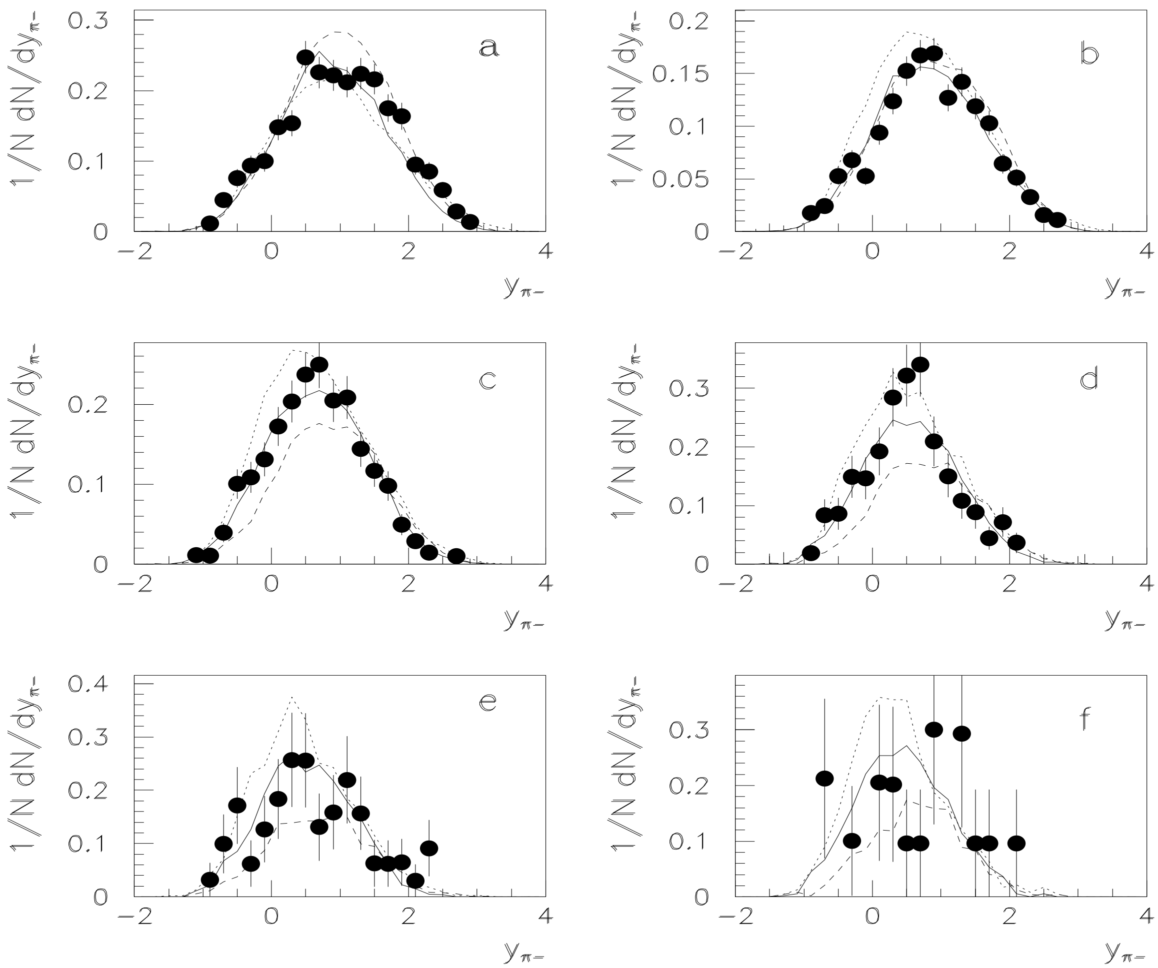

Figure 6: Rapidity distributions of π^--mesons at different Q. Notation is the same as on the previous figures.

In the group at Q=2 (Fig. 6b), CEM assumes the preferential production of π^--mesons in the fragmentation region of the target nucleus. It takes place in the other groups of the pC-interactions (Fig. 6 c, d, e, f). The calculations by the DFRITIOF model reproduce qualitatively and quantitatively the experimental spectra of π^--mesons (Fig. 6).

Let us turn to the rapidity distributions of π^+-mesons in the pC-events at Q=1, 2, 3 (Fig. 7). At Q=1 CEM and the FRITIOF model with Δ-isobars underestimate the yield of π^+-mesons over a range $0.5 < y < 1.5$ (Fig. 7a). CEM gives a larger multiplicity of π^+-mesons in the fragmentation region of the target nucleus as in the case of π^--mesons. The FRITIOF model without Δ-isobars exceeds the multiplicities at Q=1, 2 (Fig. 7a,

7b), and reduces the yield of π^+-mesons in the multi-nucleon collisions (Fig. 7 c, d, e, f). Taking into account Δ-isobars in the FRITIOF model promotes an insignificant increase of π^+-meson production in the fragmentation region of the target nucleus. It is insufficiently for the quantitative description of the experimental spectra of π^+-mesons.

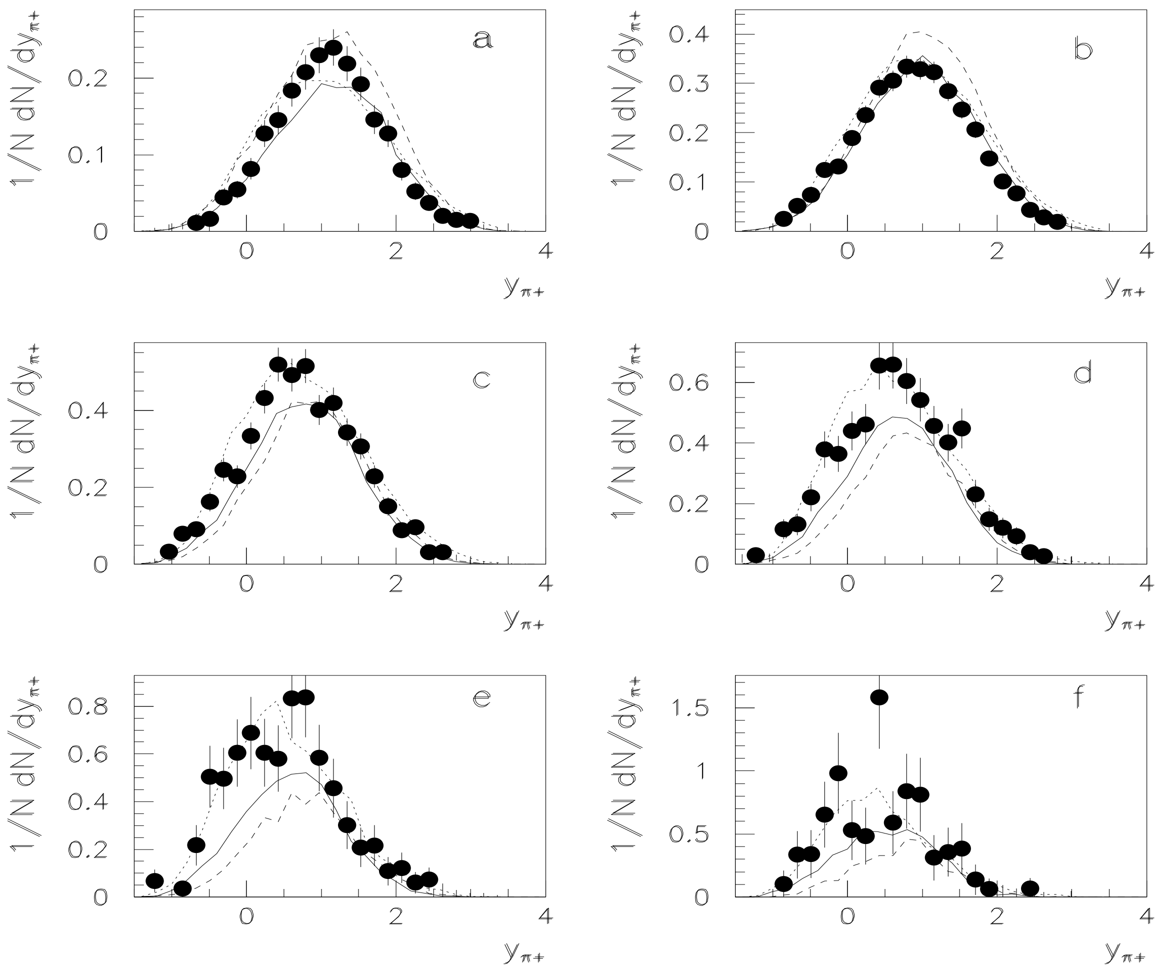

Figure 7: Rapidity distributions of π^+-mesons at different Q. Notation is the same as on the previous figures.

The models reproduce better the average kinematical characteristics of the participating protons in a dependence of the value Q. According to the Fig. 8a, the spectra of the participating protons are soften essential passing from the peripheral interactions to the central ones. The average momentum of the protons decreases more than in two times at changing of Q from 1 to 6. The change is connected mainly with increase of the part of the target proton among total number of the participating protons. The calculations show that at the average the momentum of the target protons is less than 1.4 GeV/c.

To study the situation more carefully, the target protons were subdivided into two groups: the first one included protons at the momentum from 0.3 up to 0.75 GeV/c, the second group contained ones at the momentum from 0.75 to 1.4 GeV/c. The greater part of the target protons has been found in the first group. The weak dependence of the average momentum on value Q is characteristic for these protons (Fig. 8b). This fact is connected, perhaps, with the small probability of inelastic scattering of the protons from the first group. The average momentum of the fast target protons ($p > 0.75$) decreases

with increase of Q. The average transverse momentum of the participating protons has no dependent on Q starting from Q=2. It is connected with a strong correlation between decrease of the average momentum of the participating protons with increase of Q, and the growth of their emission angles. This peculiarity is characteristic for the target protons (as seen in the table 3) formed most of the participating protons.

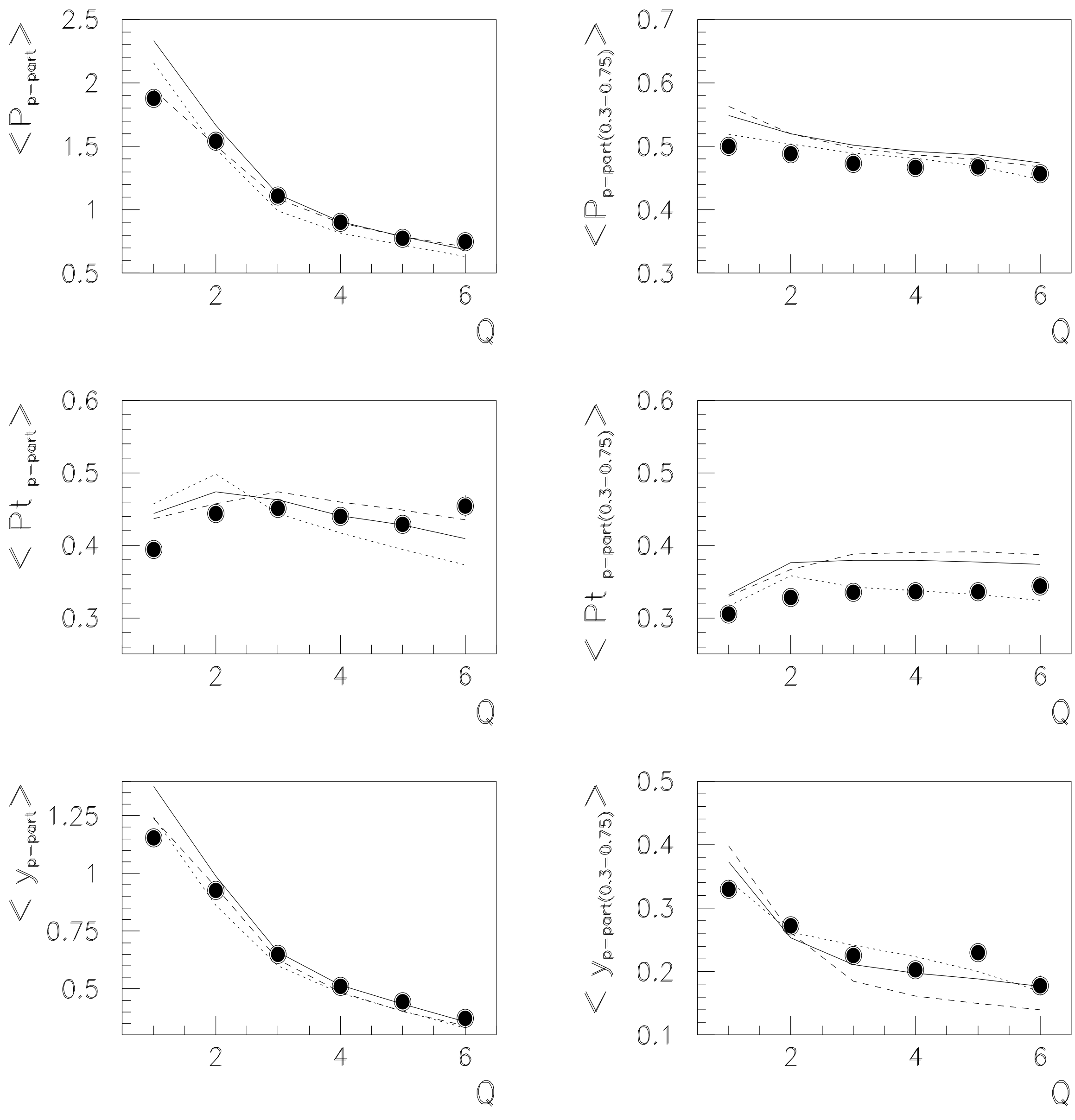

Figure 8: Average characteristics of the participating protons.

The leading protons ($p > 1.4$ GeV/c) show (as seen in the table 4) quite different dependence of the average transverse momentum on Q. Their p_T in the central interactions is in 1.2 – 2 times higher than in the peripheral ones. This effect does not influence practically on the average p_T of all participating protons due to small part of the leading protons among them. The central interactions are marked relatively small (25 %) decrease of the momentum of the leading protons in comparison with the peripheral interactions, but considerably (2 – 2.5 times) increase of the average emission angles (table 4).

Table 3: The average momenta and emission angles of the leading and target protons in the pC-interactions at 4.2 GeV/c at the different Q, e - experiment [5], m - the FRITIOF model with Δ- isobars.

Q		1	2	3	4	5	$\geq$6	All events
$< p_{p.part.} >$ (GeV/c)	e	2.76$\pm$0.03	2.66$\pm$0.02	2.35$\pm$0.03	2.12$\pm$0.03	2.02$\pm$0.06	2.02$\pm$0.10	2.58$\pm$0.01
$p \geq 1.4$ (GeV/c)	m	2.894$\pm$0.006	2.643$\pm$0.05	2.277$\pm$0.006	2.113$\pm$0.007	2.012$\pm$0.009	1.889$\pm$0.012	2.589$\pm$0.003
$< p_t^{p.part.} >$ (GeV/c)	e	0.424$\pm$0.011	0.519$\pm$0.006	0.594$\pm$0.013	0.625$\pm$0.022	0.682$\pm$0.049	0.816$\pm$0.076	0.519$\pm$0.005
$p \geq 1.4$ (GeV/c)	m	0.453$\pm$0.002	0.498$\pm$0.002	0.533$\pm$0.003	0.509$\pm$0.004	0.496$\pm$0.006	0.442$\pm$0.009	0.490$\pm$0.001
$< \theta_{p.part.} >$ (grad)	e	10.0$\pm$0.2	12.8$\pm$0.2	16.5$\pm$0.4	18.6$\pm$0.7	21.2$\pm$1.7	26.9$\pm$3.4	13.3$\pm$0.1
$p \geq 1.4$ (GeV/c)	m	10.67$\pm$0.06	12.84$\pm$0.06	15.4$\pm$0.1	15.6$\pm$0.2	15.7$\pm$0.2	14.5$\pm$0.3	12.94$\pm$0.04
$< p_{p.part.} >$ (GeV/c)	e	0.764$\pm$0.008	0.717$\pm$0.004	0.665$\pm$0.005	0.638$\pm$0.007	0.613$\pm$0.011	0.594$\pm$0.017	0.687$\pm$0.003
0.3$\leq p <$1.4 (GeV/c)	m	0.874$\pm$0.003	0.768$\pm$0.002	0.690$\pm$0.002	0.650$\pm$0.002	0.621$\pm$0.002	0.586$\pm$0.002	0.692$\pm$0.001
$< p_t^{p.part.} >$ (GeV/c)	e	0.357$\pm$0.005	0.388$\pm$0.002	0.400$\pm$0.004	0.400$\pm$0.005	0.396$\pm$0.008	0.410$\pm$0.012	0.391$\pm$0.002
0.3$\leq p <$1.4 (GeV/c)	m	0.418$\pm$0.002	0.451$\pm$0.001	0.437$\pm$0.001	0.427$\pm$0.001	0.418$\pm$0.001	0.407$\pm$0.001	0.431$\pm$0.001
$< \theta_{p.part.} >$ (grad)	e	35.4$\pm$0.6	45.3$\pm$0.3	50.5$\pm$0.5	54.4$\pm$0.8	52.7$\pm$1.2	59.8$\pm$2.1	47.1$\pm$0.2
0.3$\leq p <$1.4 (GeV/c)	m	33.2$\pm$0.2	46.4$\pm$0.2	52.9$\pm$0.2	55.7$\pm$0.2	57.8$\pm$0.2	60.1$\pm$0.3	52.1$\pm$0.1

Going from the peripheral interactions enriched by NN-interactions to the central ones, the average value of the rapidity of the participating protons displaces from the value 1.1 to a smaller one. The y-distributions of the participating protons (Fig. 9) show, that CEM describes unsatisfactory pn-interactions (as seen in the group at Q=1 and y=1.5). The same minimum in the calculations is in the group at Q=2. This minimum is caused by the poor reproduction of the proton spectra of NN-collisions by CEM.

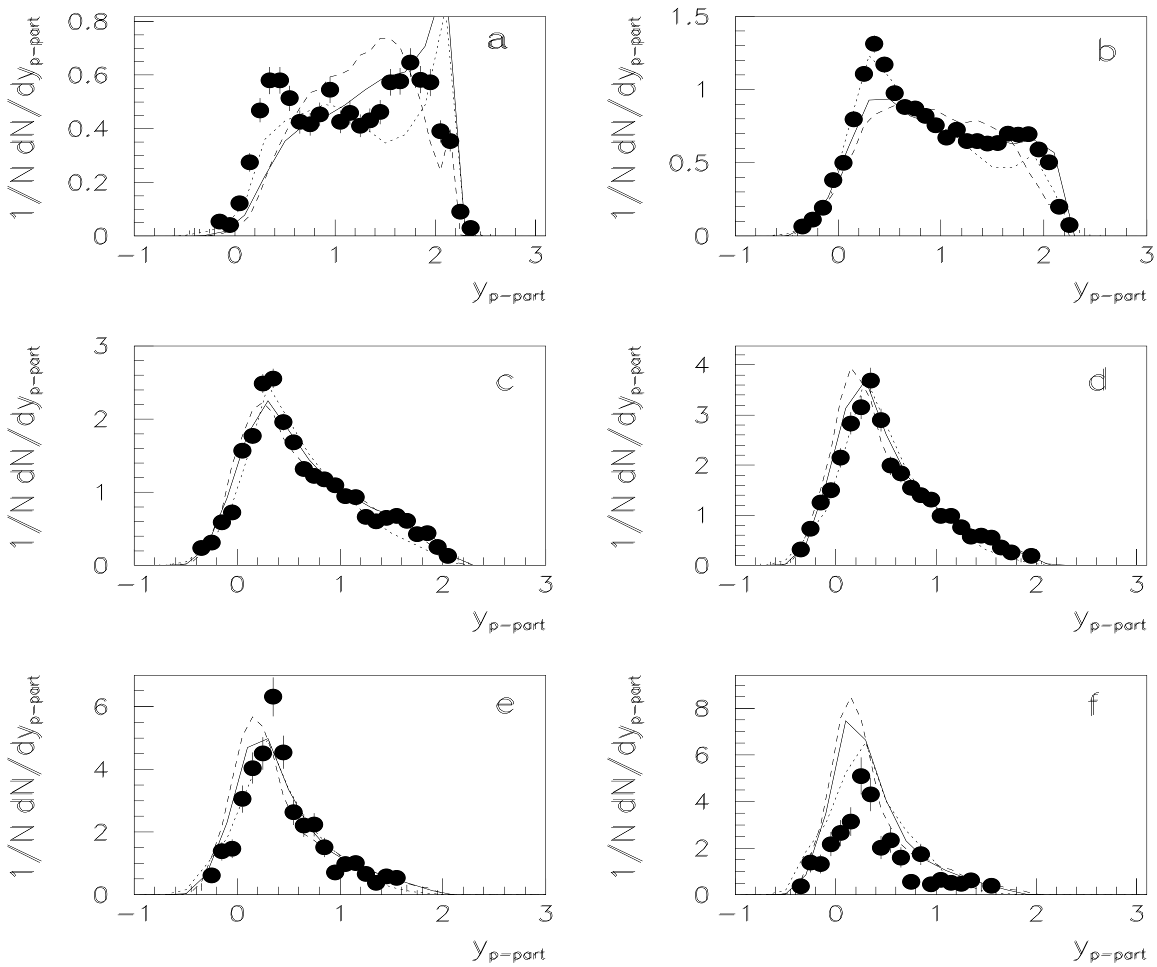

Figure 9: Rapidity distributions of the participating protons. Notation is the same as on Fig. 4.

In the events at Q=1, 2 the experimental spectra of the participating protons have a two peak structure. The wide peak at $y \sim 1.7$ is defined by the leading protons (with $p > 1.4$), and is similar to one existing in pn-interactions. The peak at $y \sim 0.5$ is connected maybe with the peak in the y-distributions of the π^--mesons. It is reflected the processes $n \to p + \pi^-$. The peak at $y \sim 0.5$ and Q=1 is not described by the models. However, CEM and DFRITIOF have some better situation at a description of the peak at $y \sim 0.4$ and Q=2. The elastic re-scattering of nucleons give the peak at Q=1 and $y \sim 2$ in the calculations performed by CEM and FRITIOF.

The FRITIOF model without Δ-isobars predicts an exceeding yield of the protons in the central region at Q=1, 2 (see Fig. 9a, 9b). The DFRITIOF model describes well the fast protons ($y > 1$). The calculated y-distributions are shifted to the fragmentation region

of the target nucleus with increasing of Q. The DFRITIOF model and CEM reproduce qualitatively the y-distributions of the protons in the pC-events at $Q > 2$.

In the Fig. 10, the momentum distribution of the participating protons in the six groups of the pC-interactions are presented. The model calculations are in agreement with the experimental data at $Q > 2$ (Fig. 10 c, d, e, f).

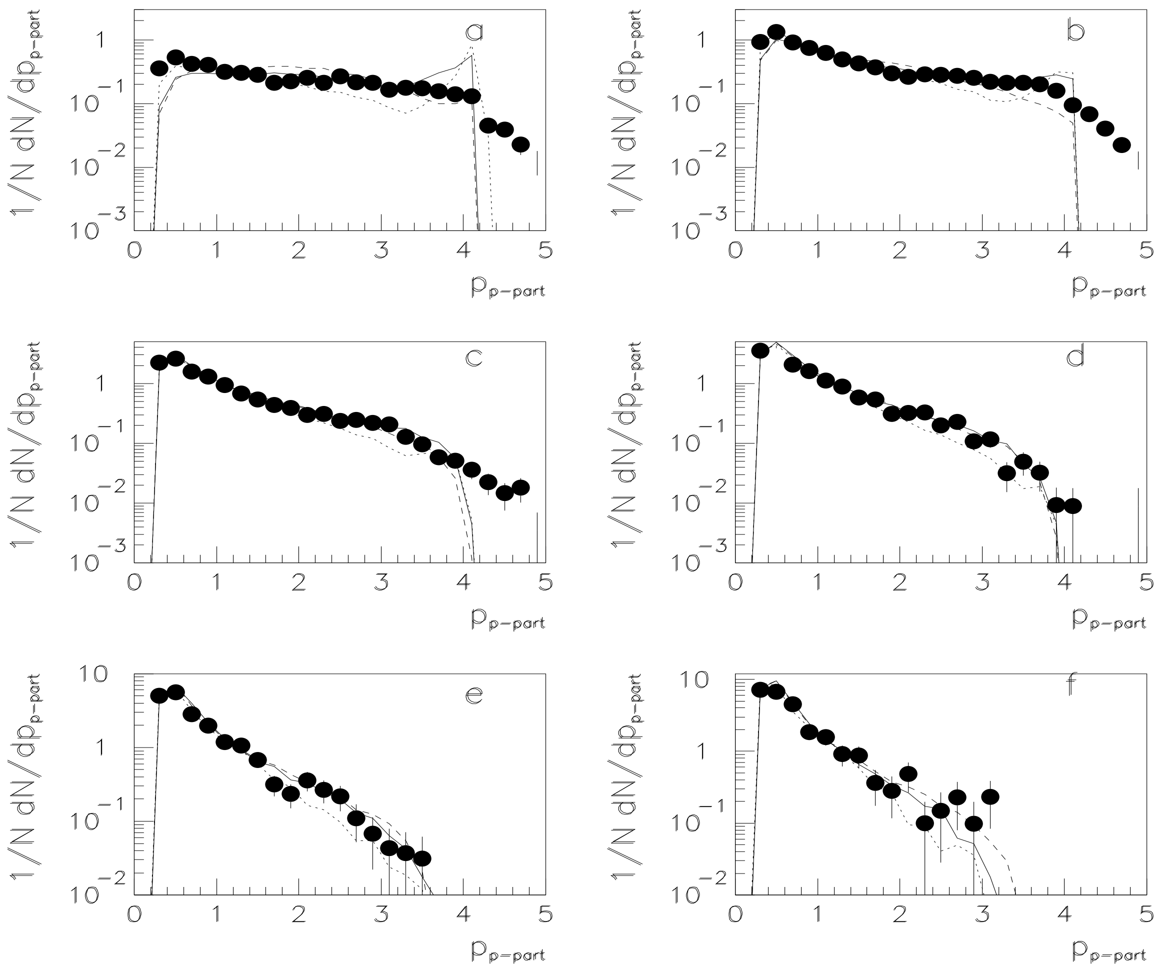

Figure 10: Momentum distributions of the participating protons. Notation is the same as on Fig. 4.

The strong differences of the predictions are seen for the pC-events at Q=1, 2 (related to the NN-interactions, basically). In the spectra calculated by CEM the peak is observed at $p \sim 4$ GeV/c and Q=1 connected with the elastic re-scattering. The model predicts a minimum at $p \sim 3$ GeV/c caused by unsatisfactory description of the NN-interactions. In the calculations by FRITIOF model without Δ-isobars, this peak is absent. However, the model predicts exceeding yield of the participating protons at the momentum ~ 2 GeV/c and underestimates the production of the soft protons. The predictions of the DFRITIOF model are near to the experimental data, with the exception of the range $p \sim 4$ GeV/c. Thus, we can conclude the used methods of the elastic re-scattering calculations are incorrect (Fig. 10a).

Agreement of the experimental data and the calculations by the DFRITIOF model is reached starting from $Q > 2$. As before, the CEM predicts the maximum at $p \sim 4$ GeV/c at Q=2.

Summary

1. The study of the pC-interactions in the dependence of the collision centrality gives the important information about demerits of the theoretical models. According to the presented data and calculations, CEM describes unsatisfactory NN-collisions, related to the group of the pC-events at Q=1, 2.

2. For the first time, non-nucleonic degrees of freedom in nuclei (Δ^+, Δ^--isobars) are taken into account in the FRITIOF model. It allows one to improve the description of the dependence of the π^--mesons multiplicity on the collision centrality, and the rapidity distributions of the secondary particles for all interactions and for the groups of the pC-events at different Q.

3. The improved FRITIOF model and CEM overestimate the elastic re-scattering of the nucleons. We believe for a correct description of the experimental data it is needed to take into account the processes of the diffraction dissociation of the nucleons in nuclei in the models.

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